



Yellowstone Falls, Yellowstone National Park (photo P. Gonzalez)

# Climate Change and Ecological Impacts at Yellowstone National Park, USA

**Patrick Gonzalez, Ph.D.**

Climate Change Response Program  
Natural Resource Stewardship and Science  
National Park Service  
1201 I Street NW  
Washington, DC 20005-5905 USA

December 4, 2012

## Introduction

Greenhouse gas emissions from vehicles, power plants, deforestation, and other human activities have increased temperatures around the world and changed other climate factors in the 20<sup>th</sup> and early 21<sup>st</sup> centuries (IPCC 2007a). Field measurements show that climate change is fundamentally altering ecosystems by shifting biomes, contributing to species extinctions, and causing numerous other changes (IPCC 2007b). To assist Yellowstone National Park (NP) in efforts to integrate climate change into resource management, this report presents results of original analyses of historical and projected climate change and a summary of published scientific findings on ecological changes related to climate change. The report only uses information from peer-reviewed scientific publications and presents results for Yellowstone NP.

## Historical Climate Changes

From 1901 to 2002, mean annual temperature increased across the Rocky Mountains (Figure 1; Gonzalez et al. 2010) and in the area that includes Yellowstone NP (Figure 2, Table 1). Although the temperature trend for the park area was not statistically significant, temperature did show a statistically significant increase at the weather station at Yellowstone NP headquarters from 1942 to 2011 (Figure 2; data from National Oceanic and Atmospheric Administration).

From 1901 to 2002, total annual precipitation increased across the Rocky Mountains (Figure 3; Gonzalez et al. 2010) and in the area that includes Yellowstone NP (Figure 4, Table 1). Although the precipitation trend for the park area was not statistically significant, precipitation showed a statistically significant decrease at the weather station at Yellowstone NP headquarters from 1942 to 2011 (Figure 2; data from National Oceanic and Atmospheric Administration).

Analyses of data from weather stations and snow courses across the western United States, including Yellowstone NP, have detected statistically significant changes in the 20<sup>th</sup> century and attributed these to climate change. The changes include increased winter temperatures (Barnett et al. 2008; Bonfils et al. 2008), decreased snowpack (Barnett et al. 2008; Pierce et al. 2008), decreased ratio of snow to rain (Pierce et al. 2008), and earlier spring streamflow (Barnett et al. 2008) from 1950 to 1999. In the Yellowstone region, climate change has shifted spring warmth 10 days earlier in the year from 1950 to 2005 (Ault et al. 2011). Analyses of snow course and tree ring data from sites across the Rocky Mountains, including Yellowstone NP, have detected melting of snowpack in the 20<sup>th</sup> century greater than any time since 1200 AD and attributed the

melting to climate change (Pederson et al. 2011). In the Yellowstone region, April 1 snow water equivalent in 2000 fell to half a standard deviation below the 1400-1950 mean.

### Historical Ecological Changes

Field measurements from Yellowstone NP have contributed to the detection of statistically significant 20<sup>th</sup> century ecological changes attributable to climate change. Multivariate analysis of wildfire across the western U.S. from 1916 to 2003 indicates that climate was the dominant factor controlling burned area, even during periods of active fire suppression (Littell et al. 2009). Climate change has also caused bark beetle outbreaks leading to the most extensive tree mortality across western North America in the last 125 years (Raffa et al. 2008). Both mountain pine and spruce beetles have killed trees in Yellowstone NP. Climate change has also shifted the winter ranges of a set of 254 bird species northward across the United States at an average rate of  $0.5 \pm 2.4 \text{ km y}^{-1}$  from 1975 to 2004 (La Sorte and Thompson 2007). In Yellowstone NP, two or three bird species moved northward into the area.

Other research has detected 20<sup>th</sup> century ecological impacts that are consistent with, but not statistically attributed, to human climate change. In mid-elevation conifer forests of the western U.S., including Yellowstone, increases in spring and summer temperatures, earlier snowmelt, and longer summers increased fire frequency 400% and burned area 650% from 1970 to 2003 (Westerling et al. 2006). The relationship of burned area in Yellowstone NP to summer temperature and rainfall from 1895 to 1989 was statistically significant (Balling et al. 1992). Amphibian species richness showed a statistically significant decline in the Lamar Valley of Yellowstone NP from 1992 to 2008 due to wetland desiccation (McMenamin et al. 2008). At four subalpine meadows north and west of Yellowstone Lake, lodgepole pine (*Pinus contorta*) has shifted upslope into the meadows since the 19<sup>th</sup> century (Jakubos and Romme 1993).

### Future Climate Projections

The Intergovernmental Panel on Climate Change (IPCC) has coordinated research groups to project possible future climates under defined greenhouse gas emissions scenarios (IPCC 2007a). The three main IPCC greenhouse gas emissions scenarios are B1 (lower emissions), A1B (medium emissions), and A2 (higher emissions). Actual global emissions are on a path above IPCC emissions scenario A2 (Friedlingstein et al. 2010).

For the three main IPCC emissions scenarios, general circulation models (GCMs) of the atmosphere project an increase in 21<sup>st</sup> century temperature seven to 11 times the amount of historical 20<sup>th</sup> century warming in Yellowstone NP (Table 1). Precipitation could increase under all three emissions scenarios (Table 1).

Spatial analyses of the area of Yellowstone NP, using climate projections for IPCC emissions scenario A2 downscaled to 4 km x 4 km (data from Conservation International <<http://futureclimates.conservation.org>>, method of Tabor and Williams [2010]) show projected patterns of climate that may occur if we do not reduce greenhouse gas emissions. Mean annual temperature could increase  $4.4 \pm 1.2^\circ \text{C}$  by 2100 AD (Figure 5). The temperature projections of the 18 GCMs are generally in close agreement, with a coefficient of variation (the standard deviation as a fraction of the mean) of 0.27, indicating that the temperature uncertainty is approximately one-fourth of the mean, although uncertainty is higher than in surrounding areas (Figure 6). Under emissions scenario A2, the length of the growing season could increase 20-25 days between the periods 1980-2000 and 2041-2070 (Kunkel et al. in review).

Most of the GCMs project increased precipitation. The GCMs show an average  $5 \pm 8\%$  increase in precipitation under IPCC emissions scenario A2 (Figure 7), with 10 of 18 GCMs projecting increases (Figure 8). The coefficient of variation of the precipitation projections is 0.22, indicating that the precipitation uncertainty is approximately one-fifth of the mean. Taken together, the temperature and precipitation projections from the 18 GCMs form a cloud of potential future climates (Figure 9). The ensemble mean reflects the central tendency of the projections, but the uncertainty for the precipitation projections is large.

Projections indicate potential changes in the frequency of extreme temperature and precipitation events. Modeling under emissions scenario A2 projects 32 to 37 fewer days with minimum temperature  $< 0^\circ\text{C}$  and no change in consecutive days with maximum temperature  $> 35^\circ\text{C}$ , between the periods 1980-2000 and 2041-2070 (Kunkel et al. in review). The same models project an increase of 17-27% in the number of days with precipitation  $> 2.5 \text{ cm}$  and up to six more days with precipitation  $< 3 \text{ mm}$ .

### Projected Ecological Vulnerabilities

Analyses of climate projections and modeling of ecosystem responses indicate potential vulnerabilities of species and ecosystems to future climate change. Under emissions scenario A2, warmer temperatures could increase fire frequencies in the Greater Yellowstone Ecosystem 300 to 1000% by 2100 (Westerling et al. 2011). Spatial analyses of 1901-2002 historical climate and 2071-2100 projected vegetation and classification using the IPCC (2007a) vulnerability framework indicate medium vulnerability of the Yellowstone NP area to northward and upslope shifts of the grassland, temperate conifer forest, and boreal conifer forest biomes (Figures 10-13, Gonzalez et al. 2010).

Tree species particularly vulnerable to range contractions due to climate change include Engelmann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*), and whitebark pine (*Pinus albicaulis*) (Bartlein et al. 1997, Schrag et al. 2008). Whitebark pine is particularly vulnerable to outbreaks of mountain pine beetle, with potential outbreaks in the Gallatin Range, Washburn Range, and Pitchstone Plateau (Logan et al. 2010). In addition, increasing evapotranspiration under climate change may cause extensive dieback of aspen (*Populus tremuloides*) (Rehfeldt et al. 2009).

Modeling of potential shifts in mammal species ranges under climate change projects that mammal species richness in Yellowstone NP could nearly double if atmospheric carbon dioxide doubles, with rodents representing half of the potential incoming species (Burns et al. 2003). Modeling of the interactions of wolves, elk, and scavengers of carrion, including bears, coyotes, and eagles, indicate that wolves may help buffer the impacts of future warming on the scavengers (Wilmers and Post 2006). With fewer elk dying in winter snows as climate change reduces snow cover, carrion from wolf kills might compensate for the loss of food to scavengers. Modeling of potential changes in fish habitat under climate change projects substantial losses of trout habitat in the Greater Yellowstone Ecosystem, with cutthroat trout (*Oncorhynchus clarkii*) particularly vulnerable in Yellowstone NP (Wenger et al. 2011).

**Table 1.** Historical and projected climate (mean  $\pm$  standard deviation (SD)) trends for the area that includes Yellowstone NP (Mitchell and Jones 2005, IPCC 2007a, Gonzalez et al. 2010). These are the results of spatial analyses of data at 50 km spatial resolution. The table also gives historical trends for the weather station at Yellowstone NP headquarters. The climate projection under IPCC emissions scenario A2 is consistent with the climate projection downscaled to 4 km spatial resolution (data from Conservation International using method of Tabor and Williams [2010]). Note “century<sup>-1</sup>” is the fractional change per century (-0.41 century<sup>-1</sup> is a decrease of 41% in a century).

	mean	SD	units
<b>Historical</b>			
temperature 1901-2002 annual average (area)	3.2	0.7	°C
temperature 1901-2002 linear trend (area)	0.4	2.5	°C century <sup>-1</sup>
temperature 1942-2011 annual average (station)	4.5	0.8	°C
temperature 1942-2011 linear trend (station)	1.6	3.1	°C century <sup>-1</sup>
precipitation 1901-2002 annual average (area)	520	80	mm y <sup>-1</sup>
precipitation 1901-2002 linear trend (area)	0.07	0.52	century <sup>-1</sup>
precipitation 1942-2011 annual average (station)	390	70	mm y <sup>-1</sup>
precipitation 1942-2011 linear trend (station)	-0.41	0.70	century <sup>-1</sup>
<b>Projected</b>			
IPCC B1 scenario (lower emissions)			
temperature 1990-2100 annual average	2.8	1.2	°C century <sup>-1</sup>
precipitation 1990-2100 annual average	0.05	0.08	century <sup>-1</sup>
IPCC A1B scenario (medium emissions)			
temperature 1990-2100 annual average	3.8	1.2	°C century <sup>-1</sup>
precipitation 1990-2100 annual average	0.04	0.08	century <sup>-1</sup>
IPCC A2 scenario (higher emissions)			
temperature 1990-2100 annual average	4.4	1.2	°C century <sup>-1</sup>
precipitation 1990-2100 annual average	0.05	0.08	century <sup>-1</sup>

Figure 1.

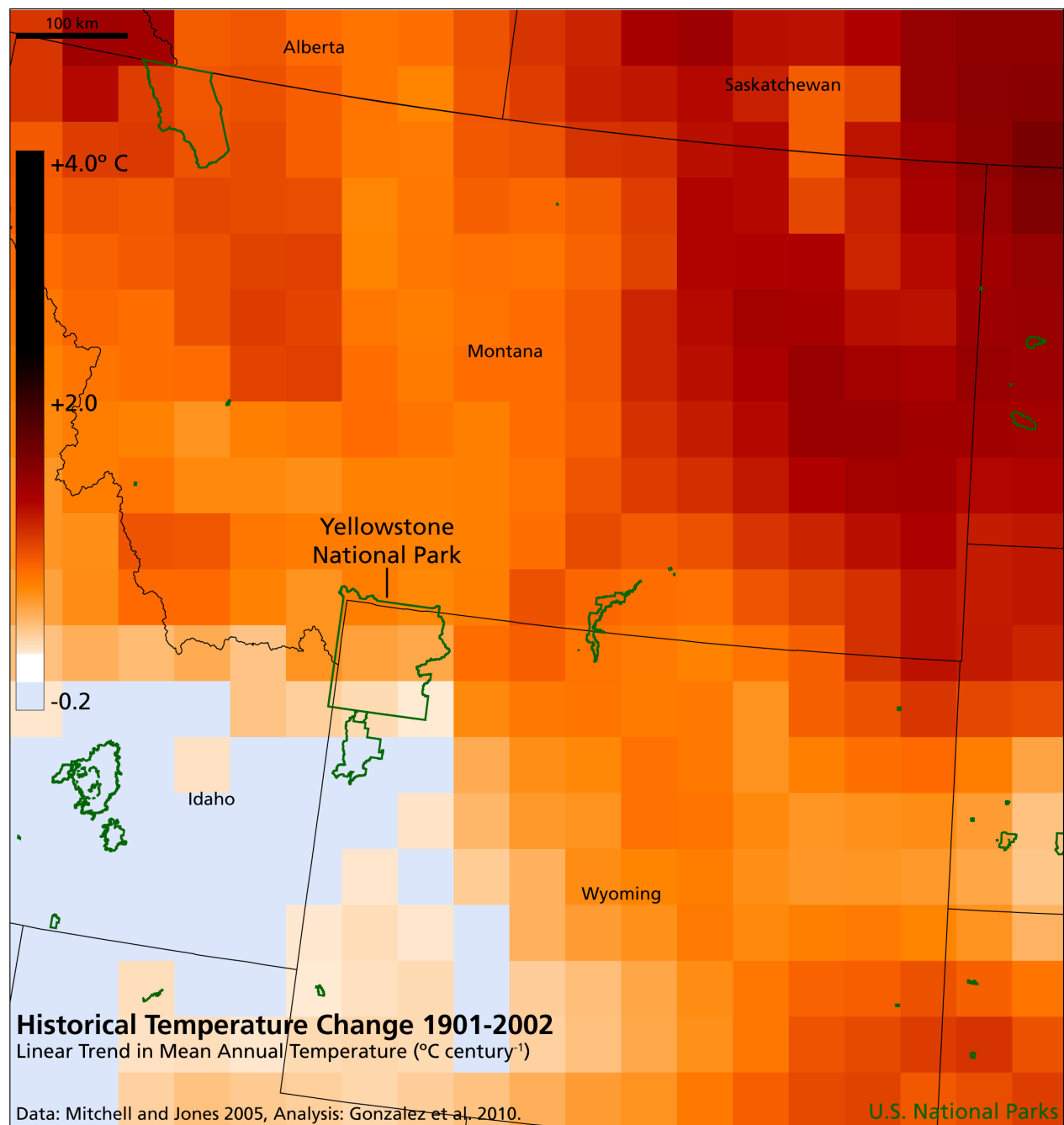
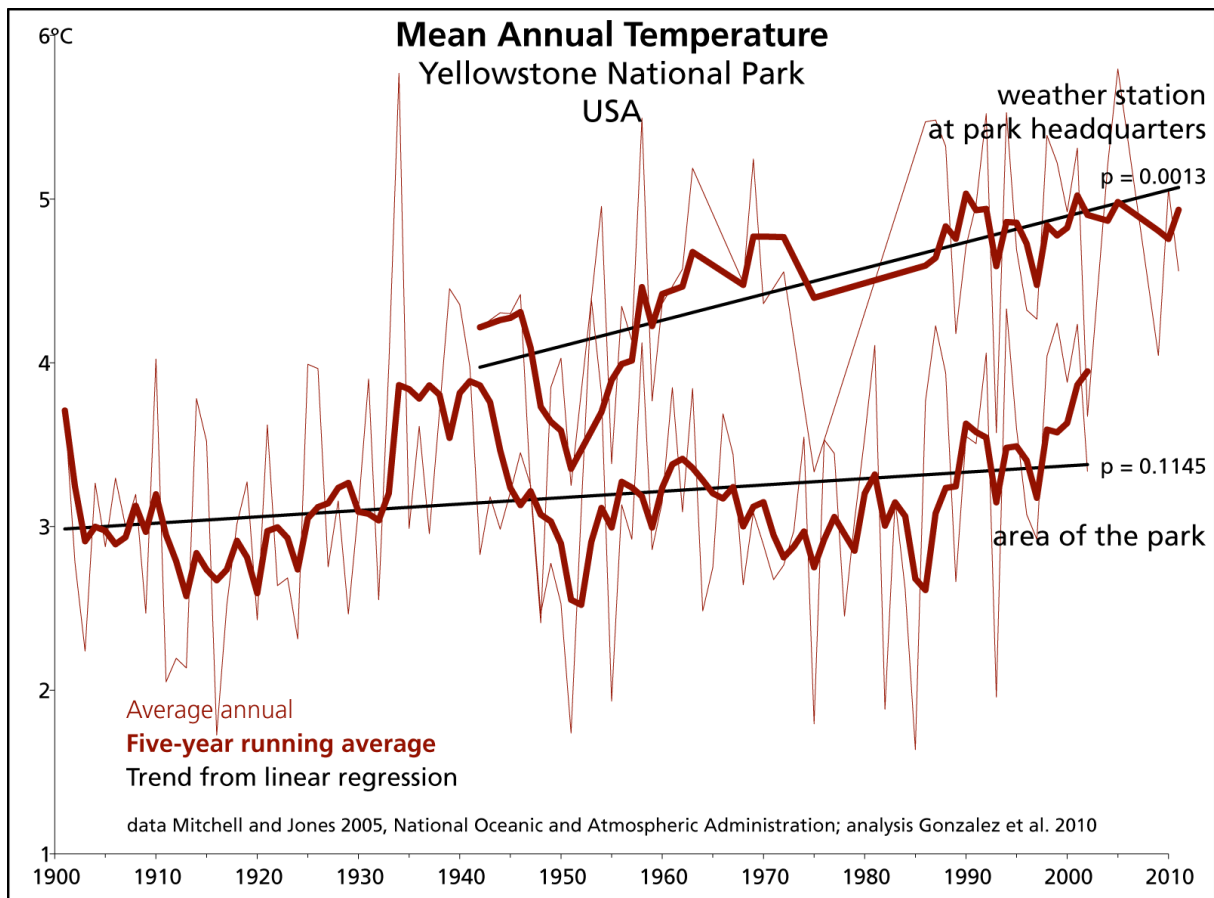


Figure 2.



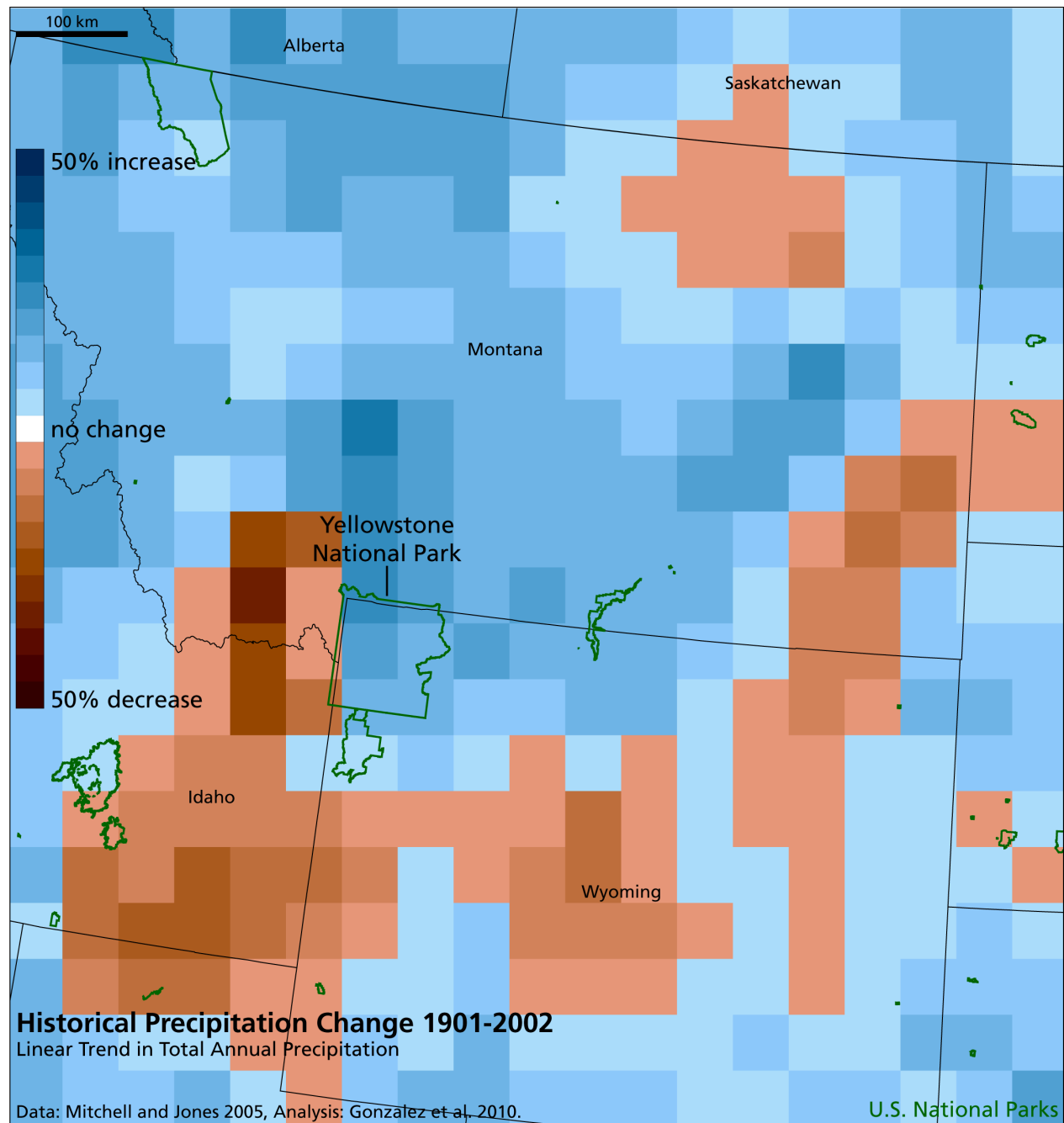
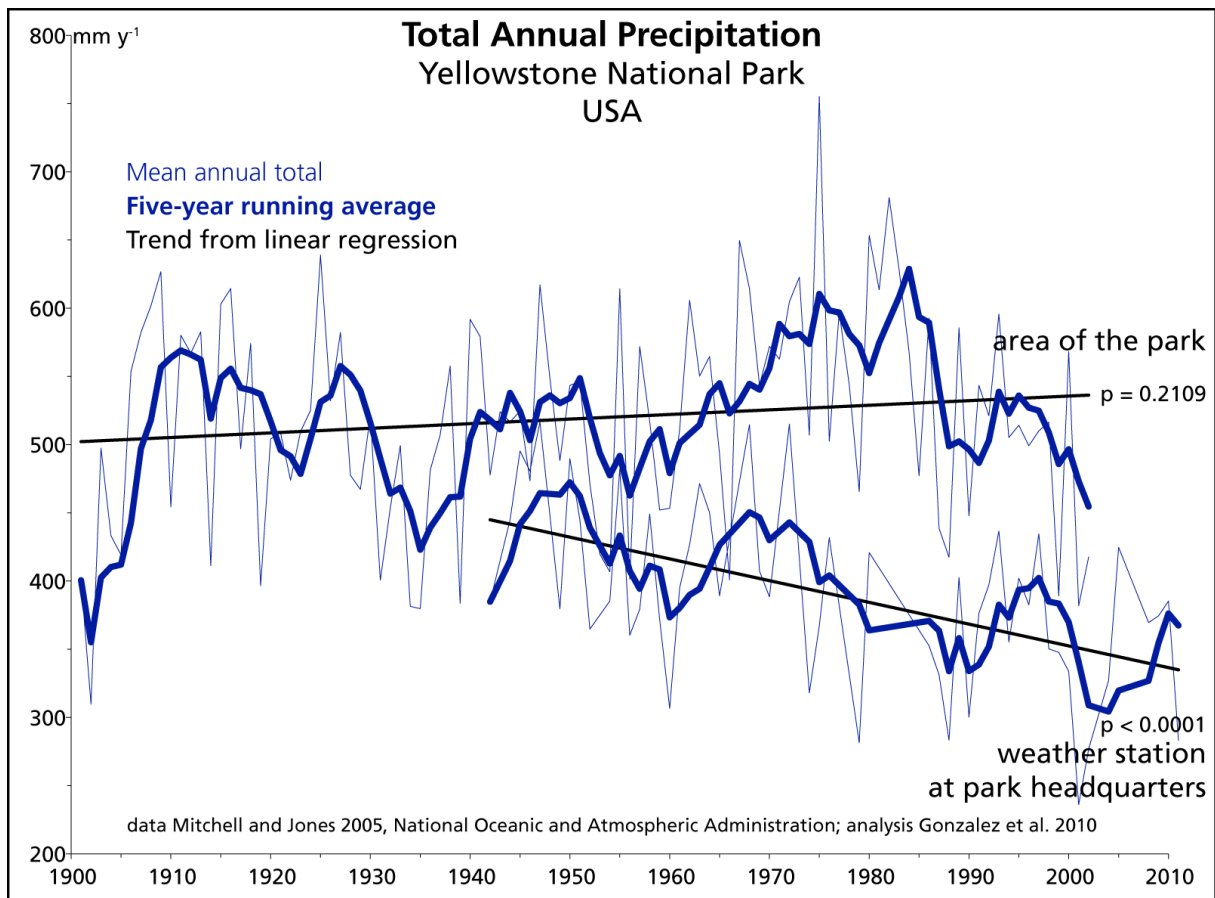
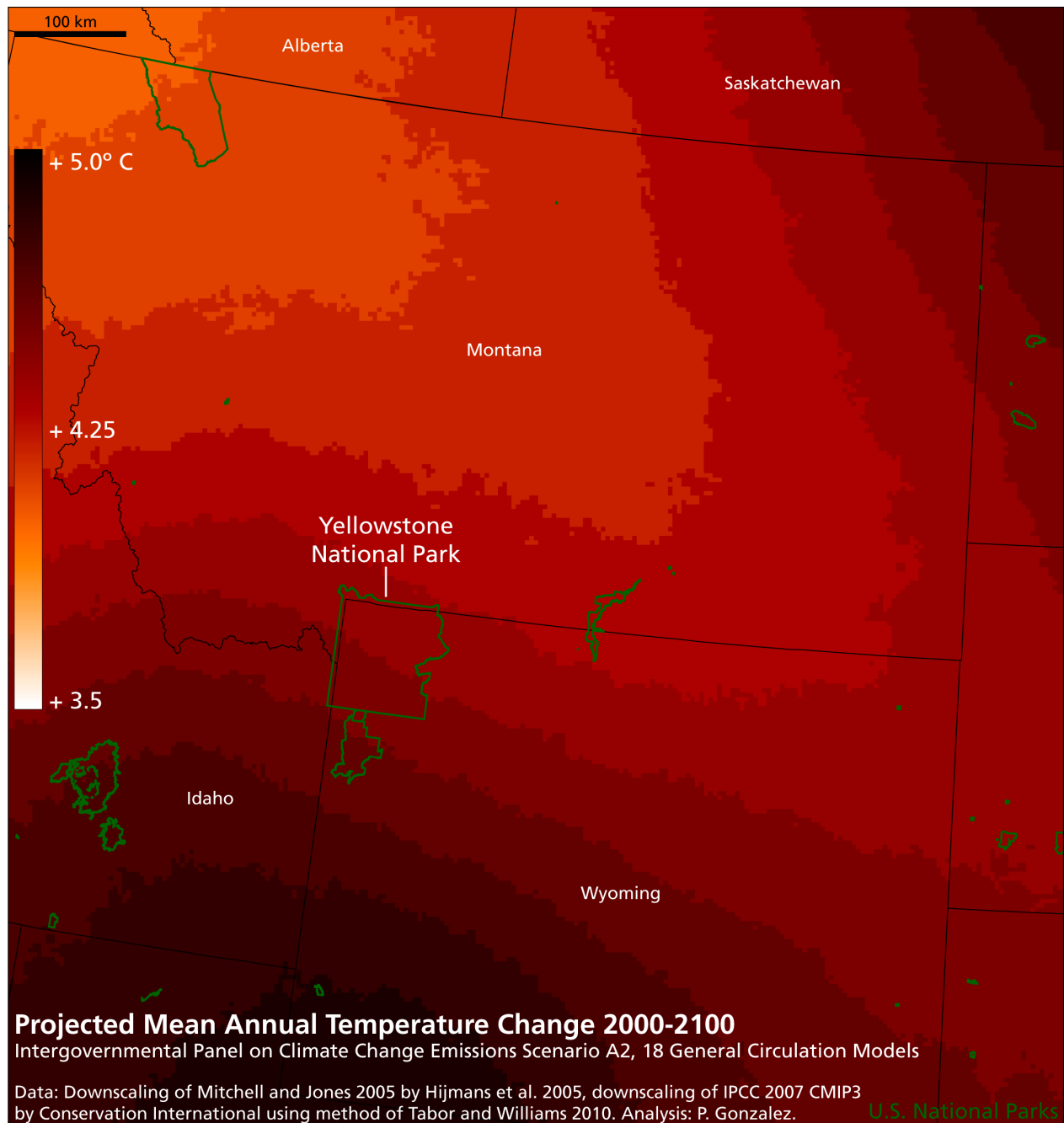
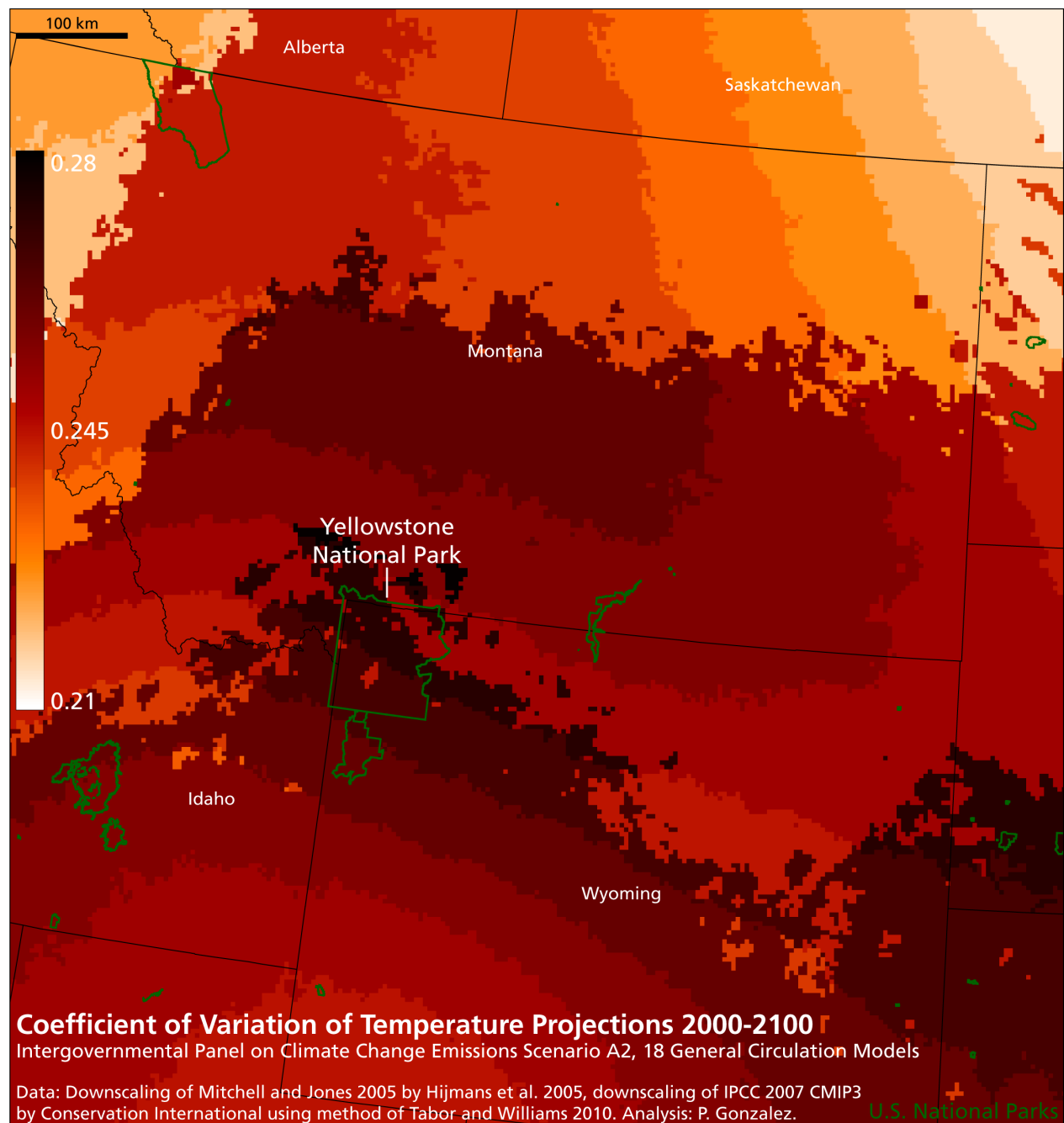
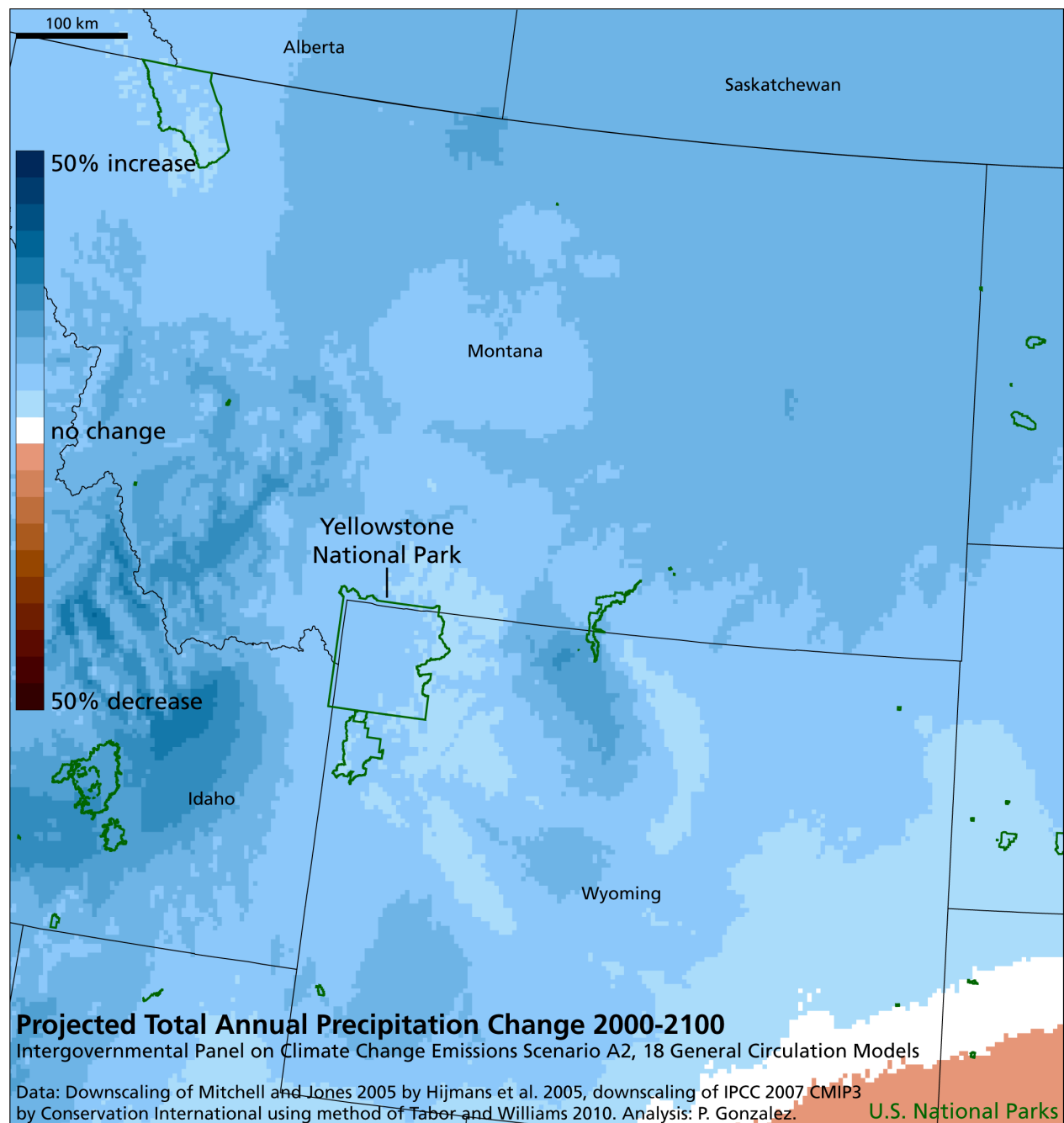
**Figure 3.**

Figure 4.



**Figure 5.**

**Figure 6.**

**Figure 7.**

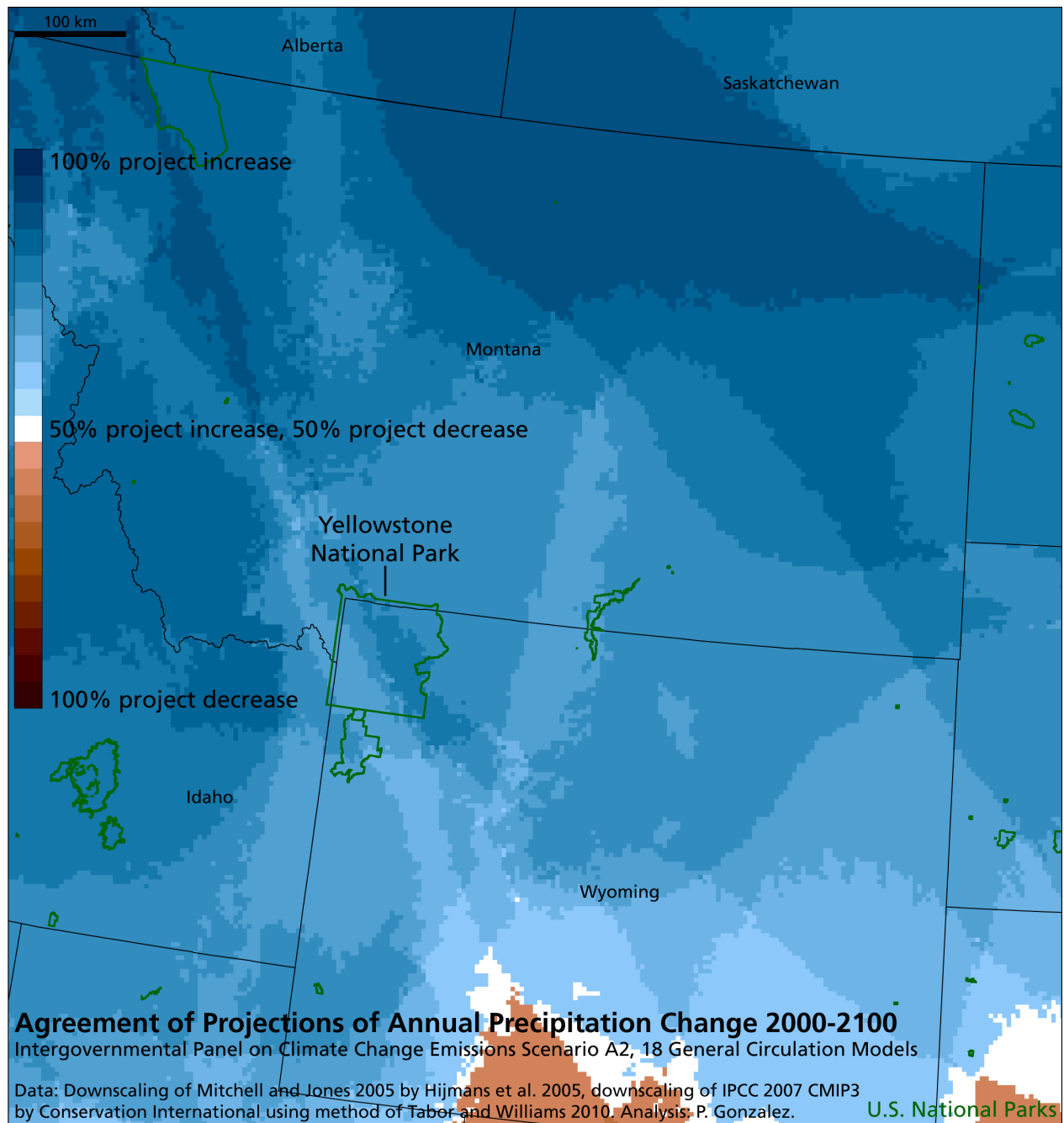
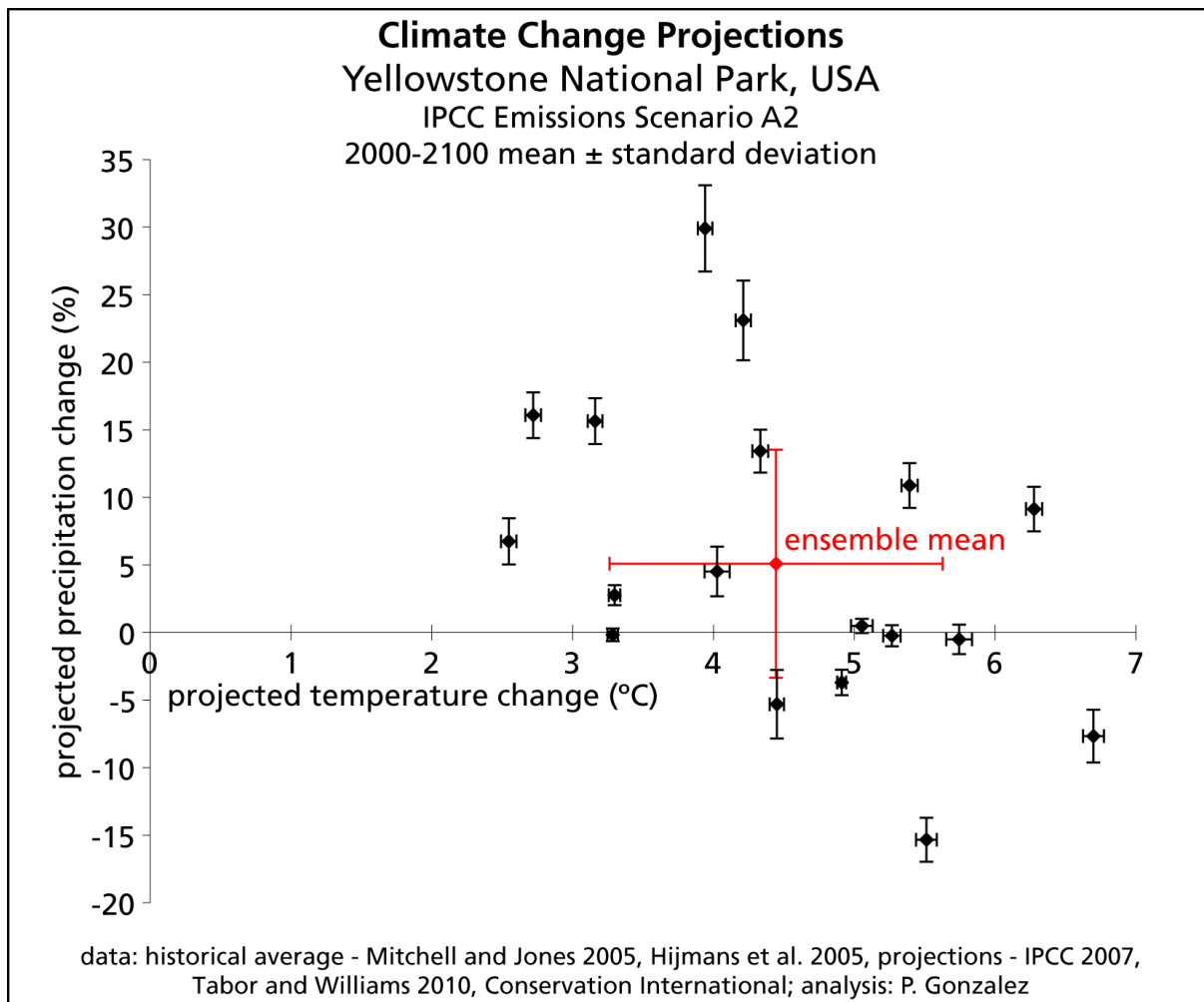
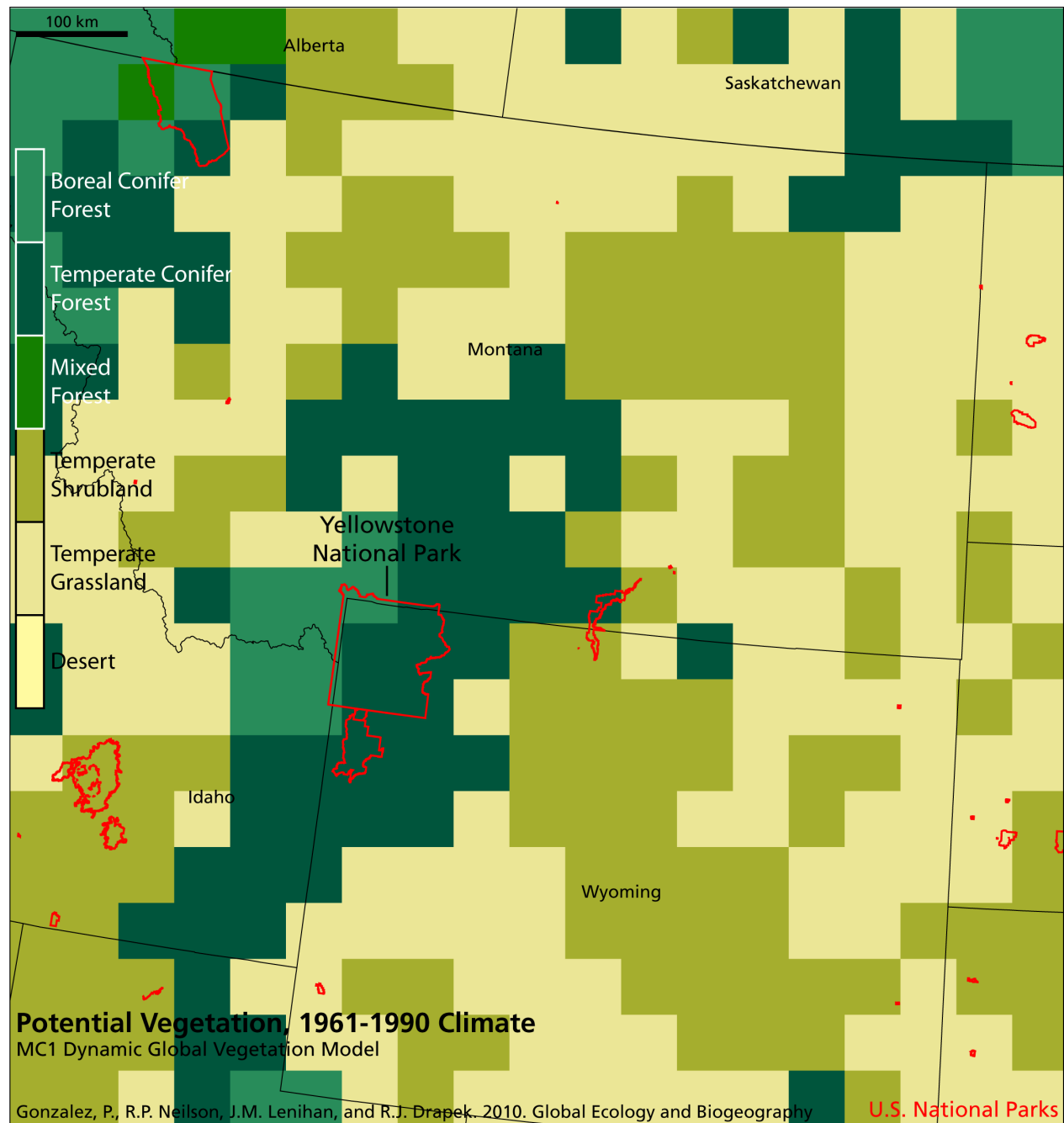
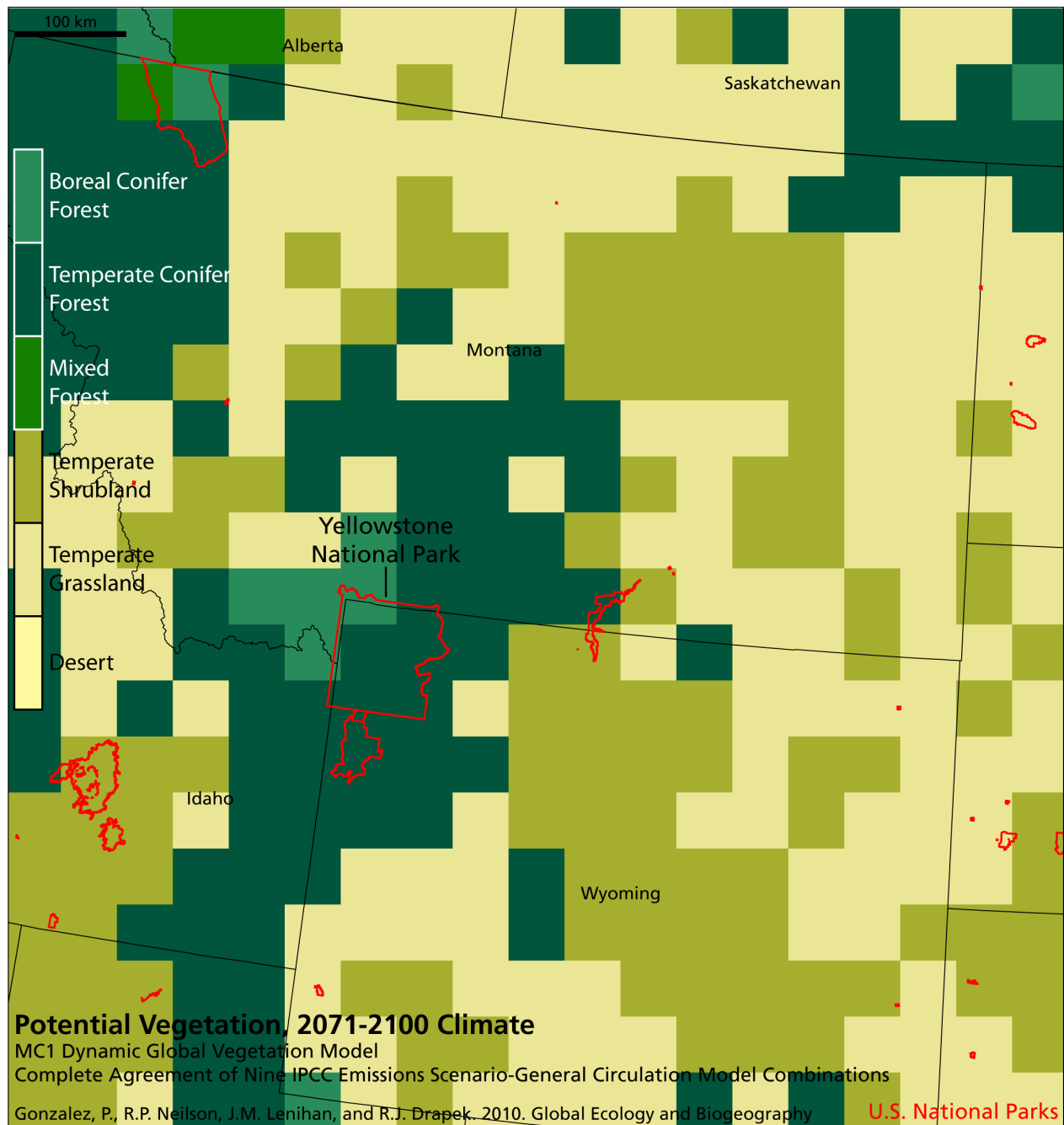
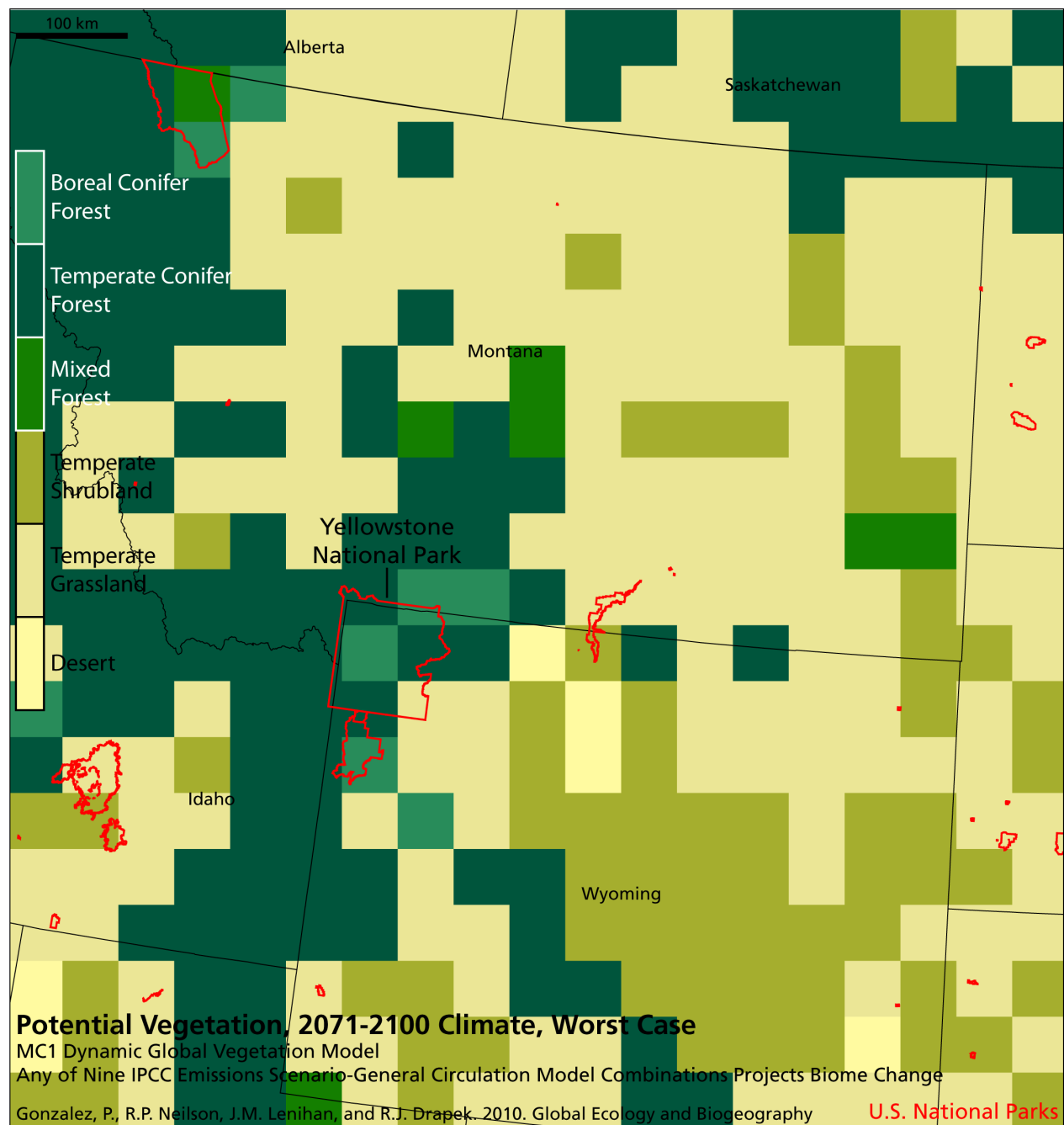
**Figure 8.**

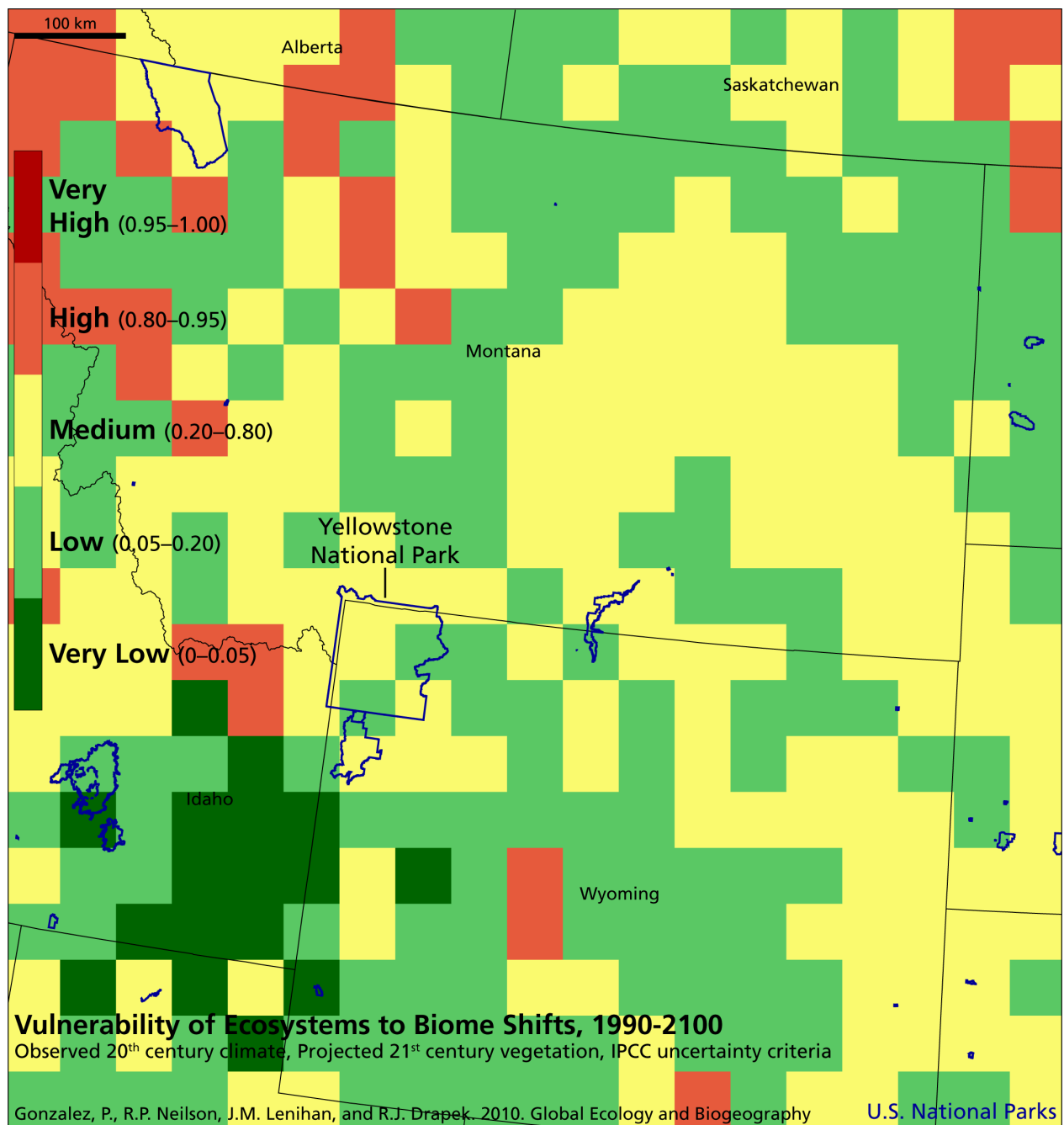
Figure 9.



**Figure 10.**

**Figure 11.**

**Figure 12.**

**Figure 13.**

## References

- Ault, T.R., A.K. Macalady, G.T. Pederson, J.L. Betancourt, and M.D. Schwartz. 2011. Northern Hemisphere modes of variability and the timing of spring in western North America. *Journal of Climate* 24: 4003-4014.
- Balling, R.C., G.A. Meyer, and S.G. Wells. 1992. Climate change in Yellowstone National Park - Is the drought-related risk of wildfires increasing? *Climatic Change* 22: 35-45.
- Barnett, T.P., D.W. Pierce, H.G. Hidalgo, C. Bonfils, B.D. Santer, T. Das, G. Bala, A.W. Wood, T. Nozawa, A.A. Mirin, D.R. Cayan, and M.D. Dettinger. 2008. Human-induced changes in the hydrology of the western United States. *Science* 319: 1080-1083.
- Bartlein, P.J., C. Whitlock, and S.L. Shafter. 1997. Future climate in the Yellowstone National Park region and its potential impact on vegetation. *Conservation Biology* 11: 782-792.
- Bonfils, C., B.D. Santer, D.W. Pierce, H.G. Hidalgo, G. Bala, T. Das, T.P. Barnett, D.R. Cayan, C. Doutriaux, A.W. Wood, A. Mirin, and T. Nozawa. 2008. Detection and attribution of temperature changes in the mountainous western United States. *Journal of Climate* 21: 6404-6424.
- Burns, C.E., K.M. Johnston, and O.J. Schmitz. 2003. Global climate change and mammalian species diversity in US national parks. *Proceedings of the National Academy of Sciences of the USA* 100: 11474-11477.
- Friedlingstein, P., R.A. Houghton, G. Marland, J. Hackler, T.A. Boden, T.J. Conway, J.G. Canadell, M.R. Raupach, P. Ciais, and C. Le Quéré. 201. Update on CO<sub>2</sub> emissions. *Nature Geoscience* 3: 811-812.
- Gonzalez, P., R.P. Neilson, J.M. Lenihan, and R.J. Drapek. 2010. Global patterns in the vulnerability of ecosystems to vegetation shifts due to climate change. *Global Ecology and Biogeography* 19: 755-768.
- Hijmans, R.J., S.E. Cameron, J.L. Parra, P.G. Jones, and A. Jarvis. 2005. Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology* 25: 1965-1978.
- Intergovernmental Panel on Climate Change (IPCC). 2007a. *Climate Change 2007: The Physical Science Basis*. Cambridge University Press, Cambridge, UK.
- Intergovernmental Panel on Climate Change (IPCC). 2007b. *Climate Change 2007: Impacts, Adaptation, and Vulnerability*. Cambridge University Press, Cambridge, UK.
- Jakubos, B. and W.H. Romme. 1993. Invasion of subalpine meadows by lodgepole pine in Yellowstone National Park, Wyoming, U.S.A. *Arctic and Alpine Research* 25: 382-390.

- Kunkel, K.E., L.E. Stevens, S.E. Stevens, E. Janssen, M.C. Kruk, D.P. Thomas, K.G. Hubbard, M.D. Shulski, N.A. Umphlett, K. Robbins, L. Romolo, A. Akyuz, T.B. Pathak, and T.R. Bergantino. in review. Climate of the U.S. Great Plains. National Climate Assessment. U.S. Global Change Research Program, Washington, DC.
- La Sorte, F.A. and F.R. Thompson. 2007. Poleward shifts in winter ranges of North American birds. *Ecology* 88: 1803-1812.
- Littell, J.S., D. McKenzie, D.L. Peterson, and A.L. Westerling. 2009. Climate and wildfire area burned in western U.S. ecoprovinces, 1916–2003. *Ecological Applications* 19: 1003-1021.
- Logan, J.A., W.W. Macfarlane, and L. Willcox. 2010. Whitebark pine vulnerability to climate-driven mountain pine beetle disturbance in the Greater Yellowstone Ecosystem. *Ecological Applications* 20: 895-902.
- McMenamin, S.K., E.A. Hadly, and C.K. Wright. 2008. Climatic change and wetland desiccation cause amphibian decline in Yellowstone National Park. *Proceedings of the National Academy of Sciences of the USA* 105: 16988-16993.
- Mitchell, T.D. and P.D. Jones. 2005. An improved method of constructing a database of monthly climate observations and associated high-resolution grids. *International Journal of Climatology* 25: 693-712.
- Pederson, G.T., S.T. Gray, C.A. Woodhouse, J.L. Betancourt, D.B. Fagre, J.S. Littell, E. Watson, B.H. Luckman, and L.J. Graumlich. 2011. The unusual nature of recent snowpack declines in the North American Cordillera. *Science* 333: 332-335.
- Pierce, D.W., T.P., Barnett, H.G. Hidalgo. T. Das, C. Bonfils, B.D. Santer, G. Bala, M.D. Dettinger, D.R. Cayan, A. Mirin, A.W. Wood, and T. Nozawa. 2008. Attribution of declining western U.S. snowpack to human effects. *Journal of Climate* 21: 6425-6444.
- Raffa, K.F., B.H. Aukema, B.J. Bentz, A.L. Carroll, J.A. Hicke, M.G. Turner, and W.H. Romme. 2008. Cross-scale drivers of natural disturbances prone to anthropogenic amplification: The dynamics of bark beetle eruptions. *BioScience* 58: 501-517.
- Rehfeldt, G.E., D.E. Ferguson, and N.L. Crookston. 2009. Aspen, climate, and sudden decline in western USA. *Forest Ecology and Management* 258: 2353-2364.
- Schrag, A.M., A.G. Bunn, and L.J. Graumlich. 2008. Influence of bioclimatic variables on tree-line conifer distribution in the Greater Yellowstone Ecosystem: Implications for species of conservation concern. *Journal of Biogeography* 35: 698-710.
- Tabor, K. and J.W. Williams. 2010. Globally downscaled climate projections for assessing the conservation impacts of climate change. *Ecological Applications* 20: 554-565.

- Wenger, S.J., D.J. Isaak, C.H. Luce, H.M. Neville, K.D. Fausch, J.B. Dunham, D.C. Dauwalter, M.K. Young, M.M. Elsner, B.E. Rieman, A.F. Hamlet, and J.E. Williams. 2011. Flow regime, temperature, and biotic interactions drive differential declines of trout species under climate change. *Proceedings of the National Academy of Sciences of the USA* 108: 14 175-14 180.
- Westerling, A., H.G. Hidalgo, D.R. Cayan, and T.W. Swetnam. 2006. Warming and earlier Spring increase western U.S. forest wildfire activity. *Science* 313: 940-943.
- Westerling, A.L., M.G. Turner, E.A.H. Smithwick, W.H. Romme, and M.G. Ryan. 2011. Continued warming could transform Greater Yellowstone fire regimes by mid-21st century. *Proceedings of the National Academy of Sciences of the USA* 108: 13 165-13 170.
- Wilmers, C.C. and E. Post. 2006. Predicting the influence of wolf-provided carrion on scavenger community dynamics under climate change scenarios. *Global Change Biology* 12: 403-409.